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BAMBOO PRODUCTION RESEARCH AT SAVANNAH, GEORGIA, 1956-77

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BAMBOO PRODUCTION RESEARCH AT SAVANNAH, GEORGIA, 1956-77

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ABSTRACT

This report presents detailed information on Temperate Zone bamboo research. Included are a botanical description and experimental data on yields, response to fertilizers, methods of propagation, and flowering. The yields of six *Phyllostachys* species following initial establishment were low, ranging from 0.71 ton for *P. bambusoides* to 1.83 tons for *P. propinqua. P. makinoi* and *P. propinqua* showed promise for quick establishment and short cutting cycle. There were significant differences in yield among the cutting cycles of two species: for *P. makinoi*, a 2-year regrowth produced a yield significantly greater than that of a 1-year regrowth, while for *P. purpurata*, a 3-year regrowth was significantly greater than a 1-year regrowth. There were no significant differences in yield among the different cutting cycles for the other species, but there was an overall trend toward increased yields with increased length of cutting cycle. Yields in a mature grove of *P. bambusoides* over a period of 8 years increased with the number of hours at temperatures below 40° F, indicating that cold periods had a beneficial effect on yields. *P. viridis* and *P. rubromarginata* responded to fertilizer treatments, especially nitrogen in the early stages of growth. Propagation of *P· viridis* by young plants with attached rhizomes was much more effective than propagation by rhizomes alone, producing about twice the yield of the rhizome method. Flowering for 10 *Phyllostachys* species lasted 4 to 7 years; some species weakened and died, but others recovered. Even though all plants of a species did not flower simultaneously, flowering did occur often among individual species within a narrow range of years. **KEYWORDS:** **bamboo (*Phyllostachys* spp.), crop yields, plant cultivation, plant propagation.**

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INTRODUCTION

Oriental bamboo was introduced into the United States in about 1860. In 1919, the U.S. Department of Agriculture began introducing and maintaining an extensive collection of hardy bamboo at what is now Agricultural Research Service's Plant Introduction Station at Savannah, Ga. This collection consists of 70 accessions, including 21 species of *Phyllostachys* and 17 species of other genera, including *Sasa*, *Bambusa*, and oriental species of *Arundinaria*. The running bamboos of the genus *Phyllostachys* are adapted to temperate areas of the South and the coastal regions of the United States. Native American *Arundinaria* species are also found in the South. Because of the threat of introducing pests, the introduction of live bamboo in the vegetative state is now prohibited except for research purposes.

Bamboos are well known for their use in familiar items, such as fishing poles, shades, furniture, matting, and plant stakes. A considerable volume of bamboo is imported annually to the United States for these and other uses. Rather extensive use is made of bamboo in Asia for structural purposes and for food (shoots of many species). Some species are known for their use as ornamentals and as hedges or screening plants. Bamboos have been used in China for paper for almost 2,000 years. In 1971, Seth (*11*)[5] reported that bamboo constitutes 67 percent of the raw materials used for pulping in India. The most important species there is *Dendrocalamus strictus*, a tropical clump bamboo. The clump bamboos, which are largely unadapted to the continental United States, are often quite large and usually have longer culm fibers than the temperate, running bamboos. They are represented in the collection only by several cultivars of *Bambusa multiplex*.

The Department supported research to determine the suitability of domestically adapted species for paper pulp (*3*). Initial studies included 21 species, involving 16 species of *Phyllostachys* and 5 species of clump bamboo from Puerto Rico. Fiber characteristics of five bamboo species and compositional characteristics of these species and pine chips are given in table A–1 (appendix). Experimental bamboo pulps prepared by the Kraft and Raitt processes (*3*) have been used alone or in combination with conventional pulps to prepare a variety of paper and pulp products. Results show that any of the species studied can be used for papermaking. Several products, involving unbleached and bleached pulps, including some high-quality papers, can be suitably prepared from bamboo. Other researchers have shown the apparent suitability of *P. bambusoides* for dissolving pulp (*10*) and structural board (*9*) and also the need for additional research in reference to its usage for newsprint paper (*8*).

In a review on the status and future potential for the use of nonwood fibers in pulping, Atchison (*1*) estimated the worldwide production of bamboo pulp at 1,360,000 tons in 1972, with major tonnages from India and the People's Republic of China. He indicated an annual yield per acre of 0.75 ton (moisture free) from natural stands in India, compared with 2.0 tons from cultivated stands under good management. He also warned of the danger of stand depletion as a result of unexpected flowering. A gradual increase in bamboo usage for pulp, especially in developing countries, is anticipated.

This report presents detailed information on bamboo research conducted from 1956 to 1977 at the Plant Introduction Station. Included are a botanical description and experimental data on yields, response to fertilizer, methods of propagation, and flowering.

BOTANICAL DESCRIPTION

Bamboo is a perennial member of the Gramineae (grass) family and belongs to the tribe Bambusa. Twenty-four species and 10 horticultural forms of the genus *Phyllostachys* have been introduced and grown in the United States (*5*). The hollow or rarely solid culms (stems) are composed of distinctive nodes and internodes. Branching occurs in the upper portion of plants. Underground stems, called rhizomes, develop and may spread horizontally for considerable distances from the mother plant; this is the basis of the expression "running bamboo." The rhizomes, like the culms, contain nodes and internodes. Each node may bear a hard, fusiform bud that is appressed to the side of the rhizome. As the growing season approaches, the buds begin to enlarge. The subsequent rapid growth and elongation is referred to as "shooting." The emerging shoot contains a sheath that is very useful in species identification because of color and morphological differences. The maximum diameter of the shoot is attained at or soon after emergence from the soil, and within 6 to 8 weeks, new culms reach full height. The *Phyllostachys* species are evergreen, but old leaves are replaced in the spring each year. It is possible to determine the age of a culm by examining its leaf scars. Unlike other grasses, the leaf blade is stalked or petiolate. Rhizomes start from new culms when photosynthetized food reserves are sufficient (usually in May or June) to support growth. Rhizome growth is rapid from August through September but essentially stops in October or November.

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[5] Italic numbers in parentheses refer to items in "Literature Cited" preceding the appendix.

Bamboos rarely flower, but when flowering does occur, it may continue for 4 years or longer. For example, *P. bambusoides* (giant timber bamboo) bloomed at Chico, Calif., in 1967–68 for the first time since its establishment in 1904 (*14*). Flowering occurred on almost all culms, regardless of age, and the seeds that were collected showed good viability. However, seeds are not normally produced in abundance. Severe loss of vigor and dieback usually accompany flowering, and the entire stand may die.

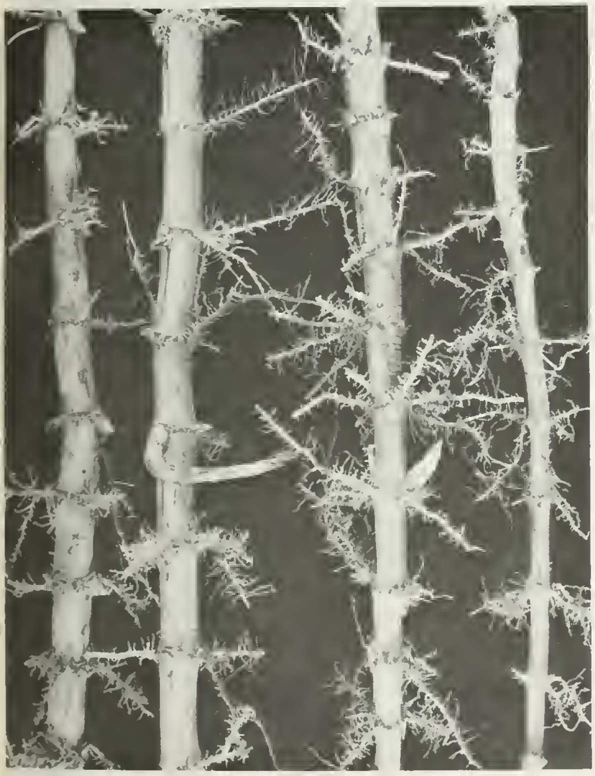

FIGURE 1.—Section of *Phyllostachys* rhizome with a developing bud. Such buds may develop into culms or new rhizomes.

Bamboo can be established by planting rhizomes, young plants, clump divisions, or seeds. The use of culm sections has met with some success for a few bamboo species, but none of the *Phyllostachys* species are propagated this way. Propagation by rhizomes is preferred because of their amenability to large-scale use. However, careful planning to assure adequate propagules is essential to the quick establishment of a large acreage.

Other publications give detailed information on botanical description, general culture, and physiology for species discussed in this report (*5*, *6*).

BAMBOO YIELD

Estimating bamboo yield is not simple. Bamboo is a large perennial grass, and a dense stand may have the appearance of a forest. Individual culms are not independent but are connected through an extensive rhizome system with many, and sometimes all, culms in the grove (fig. 1). Bamboo growth for a given year is not only dependent upon environmental conditions during that year but is heavily influenced by the conditions of previous years and may also vary independently of any environmental conditions, past or present. A comparison of clones under similar conditions in a given year may be of little value. Regrowth each year is highly variable and is a very important factor in maintaining a sustained yield.

There is little information available on the annual yields of *Phyllostachys species*. Ueda (*13*), in Japan, reported fresh-weight yields of culms per acre per year for *P. pubescens* (*P. edulis*) at 2.4 to 7.6 tons, for *P. bambusoides* (*P. reticulata*) at 2.0 to 5.6 tons, and for *P. nigra* (Henon) at 1.2 to 2.8 tons. McIlhenny (*7*), in Louisiana, obtained a yield per acre per year of 10.3 tons on a 14-year regrowth of *P. bambusoides*, or a total yield of 144.5 tons per acre. Sturkie (*12*), in Alabama, reported ovendry yields per acre per year for *P. aurea* at 1.31 tons, for *P. aureosulcata* at 0.98 ton, for *P. meyeri* at 2.57 tons, and for *P. viridis* at 1.67 tons. He also reported ovendry-weight yields

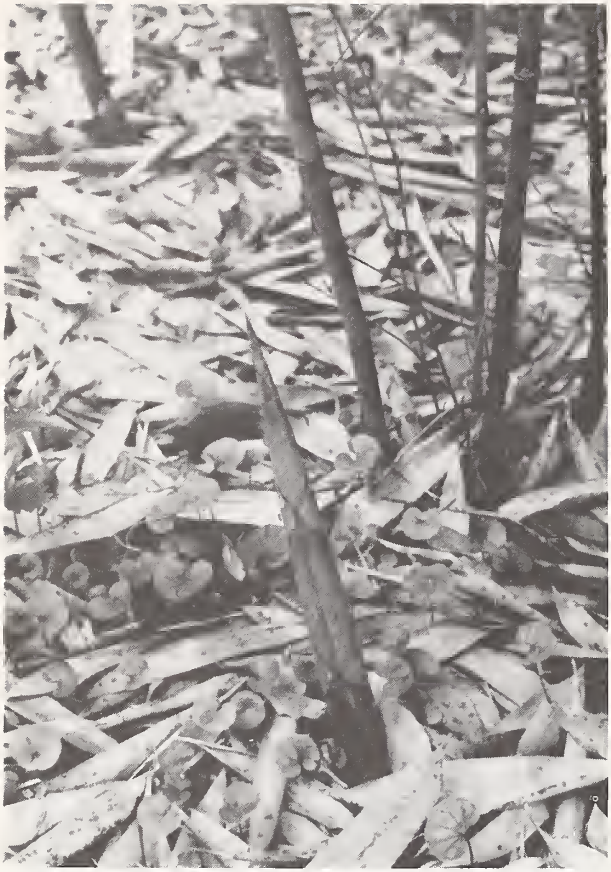

Figure 2.—*Phyllostachys rubromarginata* culms and an emerging shoot. This is a small, fast-growing, late-shooting species that is easily propagated from rhizomes.

per acre per year for *P. bambusoides* at 1.83 to 3.16 tons and for *P. rubromarginata,* the highest yielding species, at 3.43 to 5.70 tons (fig. 2).

It was assumed from the outset of bamboo research in the United States that individual culm harvesting, as practiced in many areas where bamboo is grown, would not be economically feasible. Some form of swath-cutting system was assumed to be the optimal harvesting system for commercial production. Swath cuts of 20 and 25 feet were used in the experiments at this station.

Initial-yield Experiment, 1956–65

In the winters of 1956 and 1957, experimental pulp groves of six species of *Phyllostachys* were started from clumps consisting of plants 4 years old or less. Data concerning the establishment of these groves are presented in table A–2 (appendix). Bamboo plants were well distributed over the six groves at the time of the first strip cutting in 1962. Strips were clearcut in sequence, with the 1963 strip adjacent to the 1962 strip and the 1964 strip adjacent to the 1963 strip. The strip width was 25 feet for *P. bambusoides, P. viridis,* and *P. makinoi* and 20 feet for *P. meyeri, P. purpurata,* and *P. propinqua.*

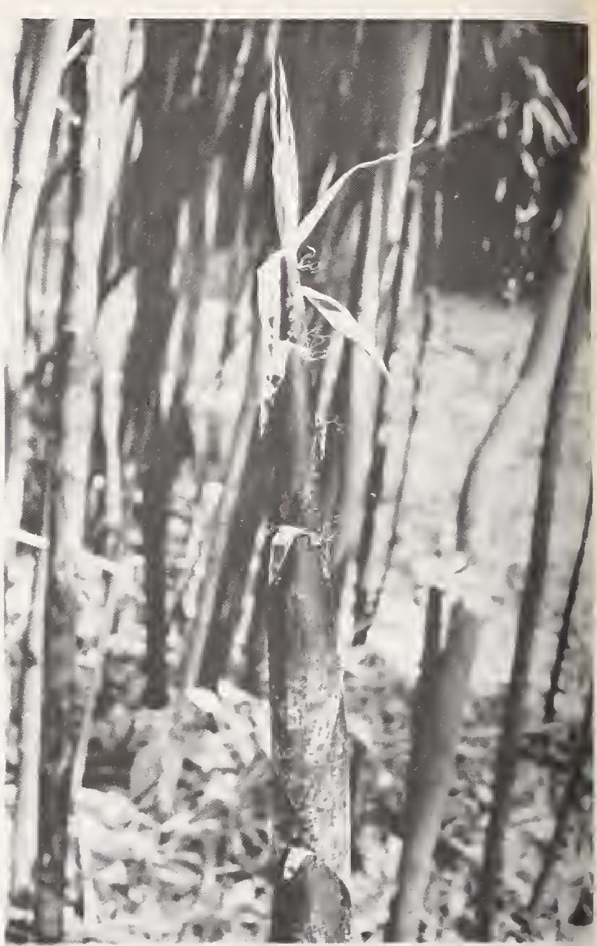

Figure 3.—*Phyllostachys bambusoides* culms and emerging shoots. This is a large species that is slow to establish.

These strip cuttings produced yield data for 7 and 8 years of initial growth for all groves, as well as data for 9 years of growth for groves established in 1956 and data for 6 years of growth for groves established in 1957. In 1965 all the harvested areas were again clearcut to produce data for 1, 2, and 3 years of regrowth.

This experiment was a test of initial yield following establishment, and it is unlikely that maximum yield for any of the species was reached. However, the data do provide an estimate of bamboo yield in its early growth (table

TABLE 1.—*Swath-cut yields, in tons per acre per year, for six* Phyllostachys *species of bamboo following establishment in 1956–57*[1]

Species	Yields[2]							
	8-yr initial growth		1-yr regrowth		2-yr regrowth		3-yr regrowth	
	Total	Per year	Total	Per year	Total	Per year	Total	Per year
P. makinoi	14.19	1.77	1.00	1.00a	5.29	2.64c	7.31	2.44bc
P. viridis	7.29	.91	1.67	1.67a	4.23	2.11a	6.06.	2.02a
P. bambusoides	5.64	.71	2.02	2.02a	3.02	1.51a	4.80	1.60a
P. meyeri	10.52	1.32	1.35	1.35a	5.32	2.66a	6.36	2.12a
P. purpurata	10.86	1.36	.27	.27ab	1.40	.70b	4.39	1.46b
P. propinqua	14.66	1.83	2.76	2.76a	6.01	3.01a	7.38	2.46a

[1] Means within a species followed by the same letter are not significantly different at the 5% level according to Duncan's multiple-range test. Means among species cannot be compared.

[2] Weight after ovendrying at 105° C.

1). The test included primarily the smaller species of *Phyllostachys,* with the exception of *P. bambusoides,* the giant timber bamboo (fig. 3). The test was not replicated with respect to species so there could be no statistical comparison of yields among different species; however, it appears that *P. bambusoides* produced low yields. Eight years is probably not long enough for establishment of a *P. bambusoides* grove. For quick establishment and short cutting cycles, *P. makinoi* and *P. propinqua* are promising.

There were significant differences in yield between two cutting cycles of two species: For *P. makinoi,* the 2-year regrowth produced a yield per acre per year significantly greater than that of the 1-year regrowth, while for *P. purpurata,* the 3-year regrowth was significantly greater than the 1-year regrowth. There were no significant differences in yield per acre per year among the different cutting cycles for the other species. However, there was an overall trend toward increased yields per acre per year with increased length of cutting cycle.

Conclusions

This test for one cutting cycle did not demonstrate that yields could be sustained in very short cutting cycles. However, the 3-year recovery growth of these species compared with the initial 8-year growth suggests that a cycle of less than 8 years could probably be sustained at approximately these yield levels and that yield on a per-year basis would be increased in subsequent cycles. Optimal cutting cycles probably vary, depending upon species and location, but the range of variation is probably not great. If the length of the cutting cycle exceeded the normal life expectancy of an individual culm, there would be losses from the death and decay of the oldest culms. If the rate of culm removal at a given cycle were greater than the rate of replacement, there would also be declines in yield. Average replacement rate should determine a minimum for the cutting cycle, and average culm life should set a maximum. Ueda (*13*) estimated the productive life of *P. bambusoides* (*P. recticulata*) culms at approximately 6 to 7 years and indicated that the replacement rate for the same species is at least 20 percent per year. Therefore, the optimal cutting cycle for *P. bambusoides* would very likely fall between 5 and 8 years. Species of smaller maximum size should be expected to tolerate slightly shorter cycles.

Established-grove Experiment, 1958–65

The most meaningful yield values should be those for sustained yield in a mature, established grove. Swath-cut yields were measured in a mature grove of *P. bambusoides* (P.I. 40842)[6] over a period of 8 years, 1958–65. It is 1.3 acres in extent, and before flowering in 1970, it produced culms near the maximum height and diameter reported for the species.

In January of 1958, a swath 25 feet wide was cut through the grove (283 feet) in a northeast direction. In the fall of 1962, 1963, and 1964, four preselected 10- by 25-ft areas were clearcut

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[6] Plant Introduction Number; see table A–2 (appendix).

TABLE 2.—*Culm density, diameter, and height and swath-cut yields for a mature* Phyllostachys bambusoides *grove, 1958–65*[1]

Year of growth	No. culms per plot	Diameter (in)	Height (ft)	Yield[2] (tons/acre/yr)
1962 SWATH CUT, 5-YEAR CYCLE				
1958	8.8b	1.6a	23.4a	1.74a
1959	11.2c	1.7a	28.3b	3.36b
1960	11.2c	1.9c	31.2c	4.18c
1961	14.5d	2.2e	35.1d	7.83d
1962	5.2a	2.1d	36.8e	2.61b
1963 SWATH CUT, 6-YEAR CYCLE				
1958	9.8b	1.6a	23.7a	1.97a
1959	10.0bc	1.6a	28.1b	2.96b
1960	8.5b	2.0c	32.5c	3.65b
1961	11.2c	2.3d	36.2d	6.26d
1962	3.8a	1.9b	33.2c	1.97a
1963	9.0b	2.2d	35.0d	5.28c
1964 SWATH CUT, 7-YEAR CYCLE				
1958	8.0b	1.9b	24.9a	1.91a
1959	9.0b	1.7a	28.2b	2.73b
1960	8.5b	2.0b	32.7c	3.48b
1961	14.0d	2.2c	35.3d	7.37d
1962	2.2a	2.4d	42.5f	1.45a
1963	11.5c	2.5d	38.2e	7.66d
1964	10.8c	2.2c	36.1d	5.86c
1965 SWATH CUT, 3-YEAR CYCLE				
1963	13.8a	2.2a	37.4a	6.38a
1964	13.8a	2.1a	37.4a	6.15a
1965	17.5a	1.8b	32.8a	5.28a

[1] Means in the same column for a given cycle followed by the same letters are not significantly different at the 5% level according to Duncan's multiple-range test.

[2] Weight after ovendrying at 105° C. Mean yield for 5-yr cycle=3.94 tons/acre/yr. Mean yield for 6-yr cycle=3.71 tons/acre/yr. Mean yield for 7-yr cycle=4.35 tons/acre/yr. Mean yield for 3-yr cycle=5.92 tons/acre/yr.

for yield determinations. In 1965 the swath cut of 1963 was harvested again. No fertilizer was applied at any time during this yield test.

The new culms for each year's regrowth were identified so that variations in regrowth yield on a year-to-year basis could be seen. The variations were large, and they obscured any real differences that might have existed among the cutting cycles (table 2). Ueda (*13*) reported that bamboo regrowth is characterized by alternating good and bad years for shoot production. Apparently, our results do not fit this pattern, or the effect was obscured by some relatively large random factor. Weather appears to have been the most likely cause of this variation. A very great variation in weather conditions can occur at Savannah. Long periods of warm weather during winter may be followed by periods at temperatures near the minimums tolerated by our bamboo species. During the years of this test, bamboo yields increased with the accumulated number of hours at temperatures below 4.4 °C (40 °F) during the winter months, suggesting that the cold periods had a beneficial effect on yields. The low yield of 1962 was preceded by a fall drought. Apparently, cold temperatures are required to maintain dormancy in the *Phyllostachys* species, and the cold requirement varies among clones within species as well as among species.

Mean yields for the 5-, 6-, and 7-year cycles were 3.94, 3.71, and 4.35 tons per acre per year, respectively. The 3-year cycle, an unusually good regrowth period, produced a yield of 5.92

tons per acre per year. This 3-year regrowth was cut from the same area in which the 5-year regrowth had been previously cut. Combining both regrowth cycles gives a mean regrowth for that area of 4.69 tons per acre per year over a period of 8 years.

Conclusions

We can conclude that bamboo will produce relatively low yields during initial establishment. During an 8-year establishment period (table 1), yields ranged from 1.83 tons per acre per year for *P. propinqua* to 0.71 ton per acre per year for *P. bambusoides*, with an average for the six species of 1.32 tons per acre per year. An established grove of *P. bambusoides* can produce a long-term average yield of more than 4.0 tons per acre per year. These results are similar to the reported yields of Sturkie (*12*) for Alabama locations. However, he achieved greater yields with *P. rubromarginata* than with the larger *P. bambusoides*. Regrowth yields fluctuate widely from year to year, not in a good-year, bad-year pattern, but apparently in response to weather factors. Cold winters and adequate rainfall appear to be the most important climatic requirements at Savannah.

RESPONSE OF BAMBOO TO FERTILIZER

Measurement of the response of bamboo to fertilizer is a problem different from that encountered with other crops. Although the size of the plot over which a given amount of fertilizer is applied is known, the area and direction of its distribution in relation to the rhizome system is unknown. Therefore, the effective fertilizer concentration is not known.

Work with the established grove of *P. bambusoides* failed to show any clear response to fertilizer. A study was initiated in 1960 to determine the response of *P. viridis*, in the early or preestablished phase of growth, to fertilizer, and in 1964 an experiment was conducted to determine the effects of nitrogen levels and fertilizer ratios on yields of *P. rubromarginata*.

New-growth Experiment, 1960–61

Rhizomes of *P. viridis*, about 1 foot long, were planted in March of 1960 to start plants for the test. Each plant consisted of a piece of original rhizome and the new rhizomes, roots, and culms emerging from it. In May the young plants were transplanted to establish plots with equal numbers of plants, and fertilizer was applied. Each plant was small relative to the plot size, and the overlap of plants from one plot to the other was limited. Nitrogen (N) was applied at rates of 25, 75, and 225 pounds per acre, using the sources urea and NH_4NO_3. The levels of phosphorus and potassium remained constant through the application of 100 pounds per acre of P_2O_5 and K_2O. One ton of lime was applied per acre in March to one-half of all the plots, and grass mulch was applied in May to one-half of the plots in each N treatment. The plants in the $2 \times 2 \times 2 \times 3$ factorial test were harvested in October of 1961.

Yields, in terms of length of culms and length of rhizomes, are reported in tables 3 and 4. Nitrogen source and mulching had no effect upon yield, as indicated by either culm or rhizome length. Liming reduced culm length but had no effect upon rhizome length. There was an interaction between liming and N level, such that the limed plots did not show a culm-length response to increasing levels of N. In other cases there was a favorable response to increasing N levels.

Culm and Rhizome Experiment, 1964–66

Plots of *P. rubromarginata* were planted in March of 1964. In 1965, fertilizers in two ratios were applied in February, June, and August at rates of 100, 200, and 300 pounds per acre. A split application equal to one-third of the total amount for each month was also applied each month. The plots were harvested in October of 1966.

The results in tables 5 and 6 indicate a significant response to N. Response to P and K, as indicated by the difference between the 3–1–2 and 4–1–2 ratios, was significant only in the case of rhizome production. However, the higher levels of P and K produced greater mean yields in nearly every case. The best single time for applying fertilizer was in February, just before initiation and rapid growth of new shoots in the spring. However, the three-way split application was significantly better than any single application. A fertilizer relatively high in N, with P and K levels adapted for

(*Continued on page 12.*)

TABLE 3.—*Effects of three levels of two nitrogen sources on* Phyllostachys viridis *culm yields, in feet per acre, with and without lime or grass-mulch applications, 1960–61*

Nitrogen source	Mean yield at N rate of[1]—			Mean yield, all N rates[2]	Mean yield, all N rates by N source[2]	Mean yield, all treatments[2]
	25 lb/acre	75 lb/acre	225 lb/acre			
			LIMED			
Ammonium nitrate:						
Mulched	11,439a	18,781gh	16,189cde	15,470a	17,497a	17,641a
Not mulched	21,371hijk	18,831fgh	18,371efg	19,524cde		
Urea:						
Mulched	18,384efg	18,740fg	15,917cd	17,680abcd	17,785a	
Not mulched	20,086ghi	15,949cd	17,637defg	17,891bcd		
Mean yield by N rate[2]	17,820a	18,075a	17,028a	....	....	....
			NOT LIMED			
Ammonium nitrate:						
Mulched	16,612cdef	18,517efg	17,108def	17,412abc	20,273b	20,307b
Not mulched	21,673ijk	24,568lm	23,163jkl	23,135f		
Urea:						
Mulched	17,391def	18,866fgh	26,007m	20,755eb	20,339b	
Not mulched	21,628ijk	14,468bc	23,677klm	19,924de		
Mean yield by N rate[2]	19,326a	19,105a	22,489b	....	....	....

[1] Means in all rows and columns for the 3 nitrogen levels followed by the same letters are not significantly different at the 5% level according to Duncan's multiple-range test.

[2] Means in a row or column followed by the same letters are not significantly different at the 5% level.

TABLE 4.—*Effects of three levels of two nitrogen sources on* Phyllostachys viridis *rhizome yields, in feet per acre, with and without lime or grass-mulch applications, 1960–61*

Nitrogen source	Mean yield at N rate of[1]—			Mean yield, all N rates[2]	Mean yield, all N rates by N source[2]	Mean yield, all treatments[2]
	25 lb/acre	75 lb/acre	225 lb/acre			
			LIMED			
Ammonium nitrate:						
Mulched	14,238a	19,721cdefg	28,612jk	20,857abc	21,998a	21,083a
Not mulched	22,385fghi	18,755cdef	28,277jk	23,139cd		
Urea:						
Mulched	25,112ij	21,068defgh	19,458cdefg	21,880abcd	20,167a	
Not mulched	18,422bcde	16,734abc	20,210cdefg	18,454a		
Mean yield by N rate[2]	20,040ab	19,068ab	24,139cd	....	....	....
			NOT LIMED			
Ammonium nitrate:						
Mulched	2,468hij	18,016bcd	22,372fghi	21,752abcd	21,982a	22,797a
Not mulched	22,307fghi	18,533cde	25,801ij	22,213abcd		
Urea:						
Mulched	20,961defgh	15,131ab	30,734l	22,274bcd	23,610a	
Not mulched	21,967efghi	22,680ghi	30,196l	24,947d		
Mean yield by N rate[2]	22,525bc	18,589a	27,275d	....	....	....

[1] Means in all rows and columns for the 3 nitrogen levels followed by the same letters are not significantly different at the 5% level according to Duncan's multiple-range test.

[2] Means in a row or column followed by the same letters are not significantly different at the 5% level.

TABLE 5.—*Effects of three nitrogen levels and two fertilizer ratios on the fresh-weight yields, in pounds per acre, of* Phyllostachys rubromarginata *culms, 1964–66*

N rate (lb/acre)	Mean yield after fertilizer application in[1]—			Mean yield, three-way split[1,2]	Mean yield by N rate[3]	Mean yield, all treatments
	February	June	August			
			3–1–2 RATIO			
100	1,764c	1,100a	1,535bc	1,470b	1,470b	2,178a
200	2,614hij	1,459b	2,309efg	2,113de	2,124c	
400	2,635hij	2,788j	2,461ghi	3,833k	2,929d	
Mean yield by time[3]	2,341bc	1,786a	2,102b	2,472cd		
			4–1–2 RATIO			
100	1,514bc	871a	1,492bc	1,753c	1,405b	2,047a
200	2,341efgh	1,612bc	1,535bc	2,701ij	2,047c	
400	2,537ghij	2,418fghi	2,134def	3,670k	2,690d	
Mean yield by time[3]	2,134b	1,633a	1,721a	2,712d		
Control mean[4]	....	....	....	....	958a	

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[1] Mean yields for the 3 months in all rows or columns at the 3 nitrogen levels followed by the same letters are not significantly different at the 5% level.

[2] Application applied each month. Total yield resulting from all applications at each N level.

[3] Means followed by the same letters are not significantly different at the 5% level.

[4] Untreated plots.

TABLE 6.—*Effects of three nitrogen levels and two fertilizer ratios on the fresh-weight yields, in pounds per acre, of* Phyllostachys rubromarginata *rhizomes, 1964–66*

N rate (lb/acre)	Mean yield after fertilizer application in[1]—			Mean yield, three-way split[1] [2]	Mean yield by N rate[3]	Mean yield, all treatments
	February	June	August			
			3–1–2 RATIO			
100	2,624fg	2,352def	2,690fgh	2,167cde	2,461b	3,093b
200	3,779mn	1,840bc	2,842ghij	3,136ijkl	2,897c	
400	4,149n	3,703m	3,158ijkl	4,628o	3,910d	
Mean yield by time[3]	3,517c	2,635ab	2,897b	3,311c		
			4–1–2 RATIO			
100	2,036cd	937a	1,677b	2,537efg	1,797a	2,657a
200	3,223jkl	2,646fg	2,058cd	2,821ghi	2,690bc	
400	3,278kl	3,485lm	3,049hijk	4,552o	3,594d	
Mean yield by time[3]	2,842b	2,352a	2,265a	3,300c		
Control mean[4]	....	....	....	....	1,884a	

[1] Mean yields for the 3 months in all rows or columns at the 3 nitrogen levels followed by the same letters are not significantly different at the 5% level.

[2] Application applied each month. Total yield resulting from all applications at each N level.

[3] Means followed by the same letters are not significantly different at the 5% level.

[4] Untreated plots.

grass production in a given area, should be the best choice.

PROPAGATION

Phyllostachys species of bamboo may be propagated by seeds, clump divisions, young plants, or rhizomes. Seeding can be ruled out as a practical method of propagation, since seed production is very sparse and occurs infrequently. Germination is poor, and subsequent seedling growth is slow.

Clump division is a method of quickly establishing a new grove of mature culms. If small clump divisions are taken, the culm should be sawed off in such a manner as to remove most of the foliage. If a large clump division is dug and the planting is well cared for, the culms may be transported and replanted with little or no pruning. This method would be applicable in circumstances where rapid establishment is desired and a large amount of bamboo propagating material is available. Usually, clumps of approximately 1 square foot are sawed off at a height of 3 feet, or just above the lowest leaves, and the roots and rhizomes are dug with an axe and spade and reset in the new area. Mechanization of this operation should be possible but has not been accomplished.

Young nursery-grown plants, dug with a section of rhizome attached, may be used as units of propagation. This method is somewhat more difficult than the use of rhizomes alone, but it may be justified by its effectiveness. Most of the cutting and digging for this procedure can be easily accomplished with existing machinery. The nursery rows are mowed or clipped at the desired level (usually about 2 feet), the rhizomes are plowed up with a turning plow, and the plants with attached rhizomes are separated by hand.

The efficiency of bamboo propagation from rhizomes is heavily influenced by the time of year in which the rhizome cuttings are taken. Much greater shoot growth was reported by DeRigo and Hawley (*2*) when rhizomes were taken in February. When rhizomes were dug before January or after March, shoot growth was very poor. Poor growth of shoots appears to be related to carbohydrate depletion of the rhizomes.

In later work by DeRigo, *Phyllostachys bissetii* rhizomes were dug in October, and all but 20 were placed in cold storage. These 20 rhizomes were evaluated for specific gravity and sugar content. Additional lots of 20 rhizomes were dug and evaluated at intervals throughout the winter. Rhizomes were also periodically taken from storage and evaluated. The rhizomes had low specific gravity (0.54) and high sugar content (3.9 percent) in October. Sugar content declined while specific gravity increased in the field material until a specific gravity of 0.72 and a sugar content of 1.85 percent were reached in February. The material from cold storage declined in both specific gravity and sugar content. After shooting had occurred in March, specific gravity dropped to 0.51 and sugar content increased to 2.3 percent. Therefore, shoot growth was not increased by cold storage when the rhizomes were dug before the buildup of carbohydrates. The winter cold period apparently had a favorable effect on shoot growth because it caused greater storage of carbohydrates in the rhizome system.

The dormancy of individual nodal buds appears to be a different problem from the growth of such buds after dormancy is broken. Our evidence indicates that successful shoot growth depends upon stored carbohydrates. The reason why some buds on a rhizome will remain dormant while others produce shoots remains unknown. Prolonged cold storage has induced shooting at every bud; however, the carbohydrate-depleted rhizome cannot sustain growth and the shoots die. The ability to induce shooting of all nodal buds of a rhizome containing a high level of stored carbohydrates would greatly increase the efficiency of rhizome propagation and alleviate one of the major difficulties in the culture of bamboo. The greater success of propagules that include a culm or a group of culms, especially since that success takes the form of increased numbers of shoots, suggests that the amount of shooting is regulated by substances produced in the culms or in their leaves. The time of shooting appears to be controlled by soil temperature. Early shooting sometimes occurs following periods of warm weather during winter, and it has often been observed that the same clones produce shoots earlier in cutover areas and on the margins of groves where the soil is exposed to sunlight than they do in shaded areas.

All *Phyllostachys* species can be propagated by rhizomes alone, although the species are not equally suited. The rhizome method offers a better possibility of mechanizing bamboo propagation than any other method, and rhizomes are better suited for long-distance transportation than clumps and young plants. Harvesting rhizomes is much like harvesting young plants except that less care is needed in harvesting and storage. The disadvantage in using rhizomes is that establishment is slower than with the other methods, except seeding, leading to weed problems and reduced initial yields. An experiment was carried out to evaluate the relative effectiveness of rhizomes and young plants as propagating materials.

Methods Experiment, 1958–60

The source of propagating materials for both the rhizome and young-plant methods was a 2-year-old nursery of *P. viridis*. The propagating material for the plant method consisted of culms that had been cut off at the sixth node and that had attached rhizomes (about 1 ft long) with five or six nodal buds. For the rhizome method, similar sections of rhizomes without attached culms were used. The plants and rhizomes were planted on June 27, 1958, and harvested on February 11, 1960. Weight, height, and diameter of culms and length of rhizomes produced were measured for each method of propagation.

The size of the plants produced by the two methods of propagation did not differ significantly (table 7). However, yield and rhizome length on a plot basis did differ. The plant method of propagation produced approximately twice the yield of the rhizome method because approximately twice as many plants were produced.

Conclusions

Large amounts of propagating material can be produced in nurseries established with rhizomes or young plants set in rows in the field. The best rate of increase for bamboo appears to be an annual doubling of the area covered. One acre of nursery 2 years old will produce enough rhizomes and plants to establish 4 acres. For harvesting, the nursery rows are mowed to a height that is dependent upon whether plants or rhizomes only are to be harvested. Then the rows are plowed, and the rhizomes or rhizomes and plants are gathered by hand. Plants and rhizomes may be stored in damp sawdust if they cannot be replanted or shipped immediately. Rhizomes destined for long distance shipment are cut to 1-foot lengths and wrapped with damp sphagnum moss and covered with waxed cheesecloth or similar waterproof wrapping.

The use of plants or clumps in propagation should enable a much more rapid establishment of a bamboo grove. The increased yields from rapid establishment and the savings on weed control for these methods versus the rhizome method would have to be balanced against their greater initial cost. The outcome of such a comparison would probably be heavily influenced by the efficiency of machinery in handling the various types of propagules.

FLOWERING

The flowering of *Phyllostachys* species (fig. 4) is one of the greatest problems in its culture.

TABLE 7.—*Effects of two methods of propagation on subsequent growth and yield of culms and rhizomes of* Phyllostachys viridis, *1958–60*

Propagating material	Growth and yield								
	No. plants per plot	Culms						Rhizome length (ft)	
		Weight[1] (g)		Diameter (in)		Height (in)			
		Per plot	Per plant[2]	Per plot	Per plant[2]	Per plot	Per plant[2]	Per plot	Per plant[2]
Rhizomes	7.3	186.2	25.5	2.46	0.34	381.25	52.2	52.9	7.2
Plants	14.0	480.0	34.3	5.25	.38	798.70	57.0	103.6	7.4
LSD[3] at 1% level	6.4	220.0	NS	2.03	NS	371.00	NS	40.0	NS

[1] Air-dried basis.

[2] NS, not significant.

[3] LSD, least significant difference.

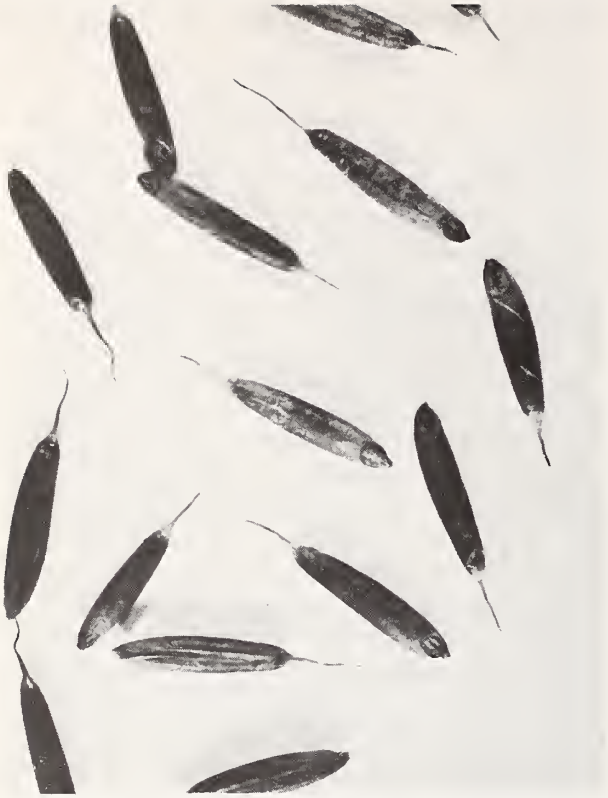

FIGURE 4.—*Phyllostachys bambusoides* seeds.

Flowering is unpredictable, usually disastrous, and on a short-term basis, useless. It occurs at long intervals of 15 to 60 years or more, depending upon the species (*6*). The few viable seed produced may be significant from an evolutionary standpoint, but they are a very inefficient means of propagation. Many seeds with undeveloped or only partly developed endosperm are found. Fully developed seed, planted soon after being collected, reportedly germinate very well; however, stored seed germinate very poorly.

Both old and new culms produce flowers. The culms of successive years are progressively smaller, and, after a few years of flowering, the grove is reduced to small bushy growth interspersed with large dead culms and is subject to intense competition from weeds. Apparently, the diversion of stored food material to flower production results in the depletion and subsequent death of all or most of the rhizome system. Nitrogen levels in the rhizomes, culms, and leaves are lower in flowering bamboo, while sugar content is higher (*13*). The addition of nitrogen fertilizer, however, has failed to restore vegetative growth. After a few years, during which every culm flowers soon after emergence, a few culms emerge and remain vegetative, and the grove gradually regains its former vigor. Thus, the onset of flowering may be sudden and total, but the emergence from flowering is usually gradual, with both flowering and vegetative culms being produced in the same area.

The pattern of decline and emergence of a large grove of *P. bambusoides* (P.I. 40842)[7] during and after flowering indicates that the following sequence occurs, as has been suggested by Ueda (*13*). First, the entire clone flowers, and the depletion and death of almost all the rhizome system results. However, some small portions of the rhizome system, possibly single buds, revert to vegetative growth, and some small vegetative culms emerge. Then, as the flowering culms and their supporting rhizomes die out, their place is taken by new vegetative rhizome growth spreading from specific locations within the area (fig. 5).

Seed may be a factor in the reestablishment of some bamboo groves. They would certainly germinate and eventually produce a new grove if conditions were favorable. However, they do not appear to have been a major factor in the reestablishment of the *P. bambusoides* grove mentioned above. Observation of seedling growth indicated that their development was too slow to give rise to the vigorous vegetative regrowth that was observed in many areas of the grove. Weed competition was such that it is doubtful whether seedlings could have survived anywhere except in the margins of the grove.

Numerous reports indicate that bamboo groves derived from a single clone will flower simultaneously, even if the groves are widely separated. It is said that all plants of a species flower at the same time. As indicated by the data in table 8, this is certainly not supported by our records, but in our collection there was often a grouping of individual accessions of a species within a narrow range of years. Between 1952 and 1966 all of the *P. nidularia* accessions flowered, and in 1965 *P. bambusoides* cv. Castillon flowered. In 1970 two other accessions of *P. bambusoides* flowered, and there were reports of *P. bambusoides* flowering elsewhere in the United States and in other parts

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[7] See footnote 6 on p. 5.

GURE 5.—Recovery growth of a grove of *Phyllostachys bambusoides* after flowering. Grove is 86 years old, and it flowered for the first time in 1970.

TABLE 8.—*Flowering of* Phyllostachys *species at Savannah, Ga.*

Species	Plant introduction No.	Years of flowering[1]	Lost or recovered
P. decora	128789	1951–	Recovered.
P. nidularia	128772	1952–	Lost.
P. rubromarginata	77000	1952–57	Recovered.
P. dulcis	73452	1910–11[2] 1953–58	Do.
P. viridi-glaucescens	77006	1955–	Lost.
P. nidularia	63757	1959–	Recovered.
P. nidularia	63696	1962–	Lost.
P. nidularia	63697	1962–	Do.
P. nidularia	67399	1963–	Do.
P. aurea	75153	1963–70	Do.
P. vivax	82047	1963–70	Do.
P. nidularia	128769	1966–71	Recovered.
P. bambusoides cv. Castillon	42659	1965–70	Lost.
P. meyeri	116768	1967–71	Recovered.
P. bambusoides	40842	1970–74	Do.
P. bambusoides	128787	1970–77	Recovery doubtful.
P. purpurata	128800	1970–77	Recovered.
P. purpurata	128805	1970–77	Recovery likely.

[1] There are no available records as to when the accessions of some species stopped flowering.

[2] Reported by Young (*15*).

of the world (*14*). Other accessions of *P. bambusoides* at the Plant Introduction Station have not yet flowered.

It is widely believed that the time of flowering of a bamboo clone is fixed genetically and is unalterable by environmental means. There has been no research that could adequately support or refute the idea; however, available evidence from flowering reports and from efforts to induce or terminate flowering suggests that it is true.

For any enterprise dependent upon a source of bamboo, the diversity of that source should be a major consideration. Maximum diversity, both within species and among similar species, should be encouraged as the only known defense against loss due to flowering. This tactic would reduce flowering to a nearly constant problem of minor magnitude rather than a large destructive event encountered once in a lifetime. Systematic means of dealing with flowering could be developed and would probably include (1) seed harvesting and the evaluation of seedlings, (2) clear cutting of the flowering area, and (3) reestablishment of the flowering area from nursery stock of another nonflowering clone or species. Although production areas would be planted to another nonflowering clone, it would be important to retain the flowering clone in the nursery and bring about its recovery. Presumably, this clone would be less likely to flower in the immediate future than other clones.

SUMMARY AND CONCLUSIONS

The yields of *Phyllostachys* species of bamboo following initial establishment are low. In an experiment involving six species, the yields per acre per year during the first 8 years ranged from 0.71 ton for *P. bambusoides* to 1.83 tons for *P. propinqua*. The test results indicate that subsequent yields increase even when a short cutting cycle is used. For an established grove of *P. bambusoides* a sustained yield of over 4 tons per acre per year can be expected.

Shoot production and growth vary greatly from one year to another, apparently in response to environmental factors. Cold winters tend to be followed by unusually high production the following spring, although cold weather, once shooting is initiated, can be very destructive. Rainfall during shooting may be critical.

As indicated by the tests with *P. viridis* and *P. rubromarginata*, bamboo will respond to fertilizer nutrients, especially nitrogen. The best time for application of fertilizer is in February.

Propagation of bamboo (*P. viridis*) by young plants with attached rhizomes is much more effective than propagation by rhizomes alone. The optimum time for digging rhizomes for propagation (*P. bissetii*) is in February when the storage of food materials in the rhizome is greatest.

Flowering occurs in the *Phyllostachys* species at long intervals of time and lasts 4 to 7 years, during which time the grove weakens and often dies. A few viable seed are usually produced. Not all clones of a species flower simultaneously, but subdivisions of a clone apparently do flower simultaneously. There is no known way to prevent bamboo from flowering, but an increase in diversity would spread the effect over time and reduce its impact.

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APPENDIX

TABLE A–1.—*Mean fiber dimensions of five bamboo species and chemical composition of these species and pine chips*

Species	Mean fiber dimensions		Ratio, length to width	Chemical composition (%)[1]		
	Length (mm)	Width (mm)		Ash	Pentosan	Lignin
Bambusa vulgaris[2]	2.28	0.0096	240:1	(3)	(3)	(3)
Phyllostachys bambusoides	1.37	.0104	132:1	2.1	22.3	32.2
P. rubromarginata	1.77	.0093	190:1	1.0	22.2	36.8
P. viridis	1.69	.0114	146:1	1.0	18.4	21.6
P. vivax	1.38	.0102	134:1	1.8	22.3	24.5
Pine chips	...	...	...	.8	14.4	27.0

[1] Analysis of the lower one-third of culms.

[2] Tropical clump bamboo.

[3] Data were not obtained.

TABLE A–2.—*Establishment of bamboo groves of* Phyllostachys *species for swath cutting, 1956–57*

Species	Plant introduction No.	Planting date	Spacing (ft)	Size of grove (acres)	Area of swath (ft)
P. makinoi	195284	January 1956	25	0.39	25×125
P. viridis	77257	do	25	1.48	25×200
P. bambusoides	40842	do	25	1.15	25×238
P. meyeri	116768	December 1956	20	.19	20×75
P. purpurata	128800	January 1957	20	.16	20×75
P. propinqua	76649	do	20	.16	20×65

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